VI

SOME APPLICATIONS OF SOUND

ONE hundred and fifteen years ago, when Chladni, who has been called the "father of acoustics", published his treatise on sound, he made the following statement: "While important progress has been made in many branches of physics, the subject of sound has always remained behind." This statement expresses with more or less truth conditions which persisted up to the time of the Great War. In 1915 the relatively few physicists who were specializing in sound found their subject of research suddenly elevated to the top level of importance, and they were called upon to solve problems of the greatest practical significance. Every one has heard of the ingenious devices invented during the war for the detection and location of submarines in the water, of airplanes in the air, of big guns on the surface of the earth, and of miners or sappers under the surface of the earth.

In the field of these inventions it has been easy to beat the sword into the plowshare, for many of the war inventions have found ready application to peace-time pursuits; and while it is impossible to give a comprehensive discussion of these matters, there are a few which can be considered here. Then there are certain constantly recurring questions, questions some of which were answered long ago, but which are continually bobbing up in different forms in literature and conversation, such as, "Why do we hear distant sounds more clearly at night than in the daytime? Or do we hear them more clearly? Do sounds travel as well in a fog as in clear air? Why do telegraph wires hum on certain occasions and not on others? Why does the pleasurable effect of a musical performance depend so greatly upon the design of the auditorium in which the performance is given?"

These questions cannot be answered without a general knowledge of the nature of sound. The Greeks heard the humming of the wind through the trees of the forest and they explained the noise by saying that it was Æolus tuning up his harp. The Esquimos hear the wind howl about their huts and tell their children that it is Tornarsuk, the demon of the cold, who rides the north-wind and freezes men who venture out. These explanations of sounds are "human" explanations, and as such are probably more interesting to many people than the scientific explanations given in terms of pressures, velocities, and the laws of hydrodynamics; but we should not get very far if we relied upon Æolus or Tornarsuk to help us locate an airplane by sound, or to correct the acoustic deficiencies of an auditorium. We are obliged to invoke the aid of the much less romantic conceptions of pressure, velocity, frequency, and wave-length.

To begin with, then, let us consider the three different aspects of every sound. The source of any noise is always some vibrating object. This object may be a water particle in a thumping radiator, a set of wheels and levers in a ticking clock, or a mass of air in the poorly designed cornice of a building, which tortures the ears of its occupants with dismal moans whenever there is a high wind, but the vibrating object is there. It is the first essential in the production of sound.

Suppose I wave my hand back and forth. Here we have a vibrating object but you hear no noise. Suppose now I increase the frequency of vibration. If I could move my hand backwards and forwards at the rate of thirty times a second you would hear a very low pitched note. As I increase the frequency of vibration the note rises continuously in pitch. If my hand vibrates fifteen thousand times a second some of you would no longer hear a sound. At thirty thousand vibrations per second, or above, no one would be able to hear the tone produced. It appears, therefore, that a vibrating object must have a frequency somewhere between thirty and thirty thousand in order to produce an audible tone.

Now to analyze the matter a little further. Every time I move my hand forward I push forward the air layer which is in immediate contact with my hand. This air layer pushes neighboring air layers forward, and in time, if I have moved my hand vigorously enough, the air layer in contact with your eardrum is pushed forward. When these air puffs, or pushes, follow each other rapidly enough, the sensation on the ear is that of a musical tone. Here we have the second component in the mechanism of sound production, namely, a series of moving puffs, or pushes, in the air. We call them condensations, and speak of the rarefactions travelling through the air, or any medium, which we call sound. The sound is present, therefore, whether or not there is any ear to hear it. If an ear is present, however, we have a third feature to deal with. The air waves beating against the eardrum set it in motion and it is this motion which produces the sensation of sound.

One of the very remarkable things which the human machine is able to do is to sort out these extremely complex motions of the tympanum and bring them at will into the consciousness of the individual. The eardrum is always responding to numerous sounds—the rushing of the wind, the singing of birds and insects, the honking of automobile horns. Even if we tried to escape all this and went down to the bottom of a deep mine, say, we should still find our eardrums ceaselessly vibrating to the noises of our own bodily processes; for example, the rushing of blood through the blood vessels. The ear may be responding to thousands of different kinds of vibrations in the air, yet the brain is able to pick out one set of vibrations, possibly those corresponding to the voices of the people behind you, and you hear those voices to the almost complete exclusion, say, of a symphony by Beethoven. The ear can be trained to detect extremely minute differences in the character of sounds. Sir William Bragg tells of a blind naturalist, Mr. Wilkinson of Leeds, who, when taking walks in the country, is able to name different varieties of trees by the character of the sounds which they reflect or produce in the wind. He knows where the meadows are by the skylarks singing over them. Blackbirds mean hedges; a hush in another direction means that at some distance away there is a forest. Some blind men avoid collisions with large objects by listening to the sound of their own footsteps. The character of the sound changes when reflecting surfaces are near.

Let us now consider some of the characteristics of sound in the open air. A good many years ago the famous physicist and lecturer, John Tyndall, made a series of important experiments in connection with the question of fog-signalling. A sound battery consisting of trumpets, whistles, a steam siren, and three small cannon was mounted on a cliff of the South Foreland near Dover. Tyndall and his companions steamed about over the sea in an effort to determine the effectiveness of the signals. Very conflicting results were obtained, the greatest distance at which the sound was audible varying as follows:

May 19,	3	and 1-3	miles
May 20,	5	and 1-2	miles
July 1,	12	and 3-4	miles
July 2,	4		miles
July 3,	3		miles,

this being a calm, clear day with a smooth sea.

The explanation of these results given by Tyndall is based upon the fact that a sound wave is reflected when it strikes an unyielding medium, and also when it strikes a yielding medium. A sound wave striking a place where the air density is small encounters a yielding medium and there is partial reflection—also if it encounters a layer of denser air reflection occurs.

These facts are sufficient to explain Tyndall's erratic results. Speaking of his observations of July 3, he says: "As I stood upon the deck of the *Irene* pondering the question, I became conscious of the exceeding power of the sun beating against my back and heating the objects near me. Beams of equal power were falling on the sea, and must have produced copious evaporation. That the vapor generated should rise and mingle with the air so as to form an absolutely homogeneous medium was in the highest degree improbable. It would be sure, I thought, to rise in invisible streams, breaking through the superincumbent air now at one point, now at another, thus rendering the air flocculent with wreaths and striæ. At the limiting surfaces of these we would have the conditions necessary to the production of partial echoes and the consequent waste of sound. Air currents of different temperatures, as far as they existed, would also contribute to the effect."

The point is, that, if the sound is reflected by all these rising currents of hot air between the observer and the sound source, it cannot pass through. A non-homogeneous atmosphere is thus not good for conducting sound. It seems probable that at night the atmosphere, not being filled with rising currents of hot air, is often more homogeneous, and hence sound may be propagated better at night than during a hot, clear day. Tyndall found, in fact, that a cloud obscuring the sun for a short time materially increased the range of his sound signals.

If this explanation of the acoustic opacity of air is correct, we ought to be able to hear the reflected sound. Tyndall decided to test his theory by finding these echoes, so he landed and stood on the shore beneath his sound battery. He says: "From the perfectly transparent air the echoes came, at first with a strength apparently little less than that of the direct sound, and then dying away." The theory, therefore, appeared to be proved.

The observations which I have described are only a few of those which have been made. Rain, snow, or fog do not produce an appreciable effect on the propagation of sound; in fact, a fog is usually associated with a fairly homogeneous atmosphere, so that we frequently find the conditions of acoustic transparency associated with the optical opacity of the fog.

There is room for important application of the principles of sound transmission which I have been considering. Take the case of a locomotive whistle. In these days, when thousands of people are killed every year at railroad crossings, engineers and inventors are doing everything possible to stop this useless loss of life. The law places great emphasis on the locomotive whistle as a safety factor. However, a scientific efficiency expert turned loose on a locomotive whistle could probably save much money and many lives. The whistle is placed behind the smokestack so its sound must traverse columns of hot gases before reaching the crossing ahead. The sound is thereby diminished in intensity and is less likely to be heard. The disadvantageous position of the whistle, therefore, can result in the loss of life. On the other hand, if the same number of people are to be killed every year, that is, if the same sound intensity is to be used for the prospective victims, then much coal could be saved by placing the whistle in front of the smokestack and blowing it less vigorously. Professor A. L. Foley, to whom this idea is due, has figured, according to the daily press, that 2,434,026 tons of coal are consumed annually in generating steam to blow the nation's locomotive whistles. The cost of this coal is over seven million dollars. Instead of the low-pitched, or "chimes" whistle now in use, Professor Foley advocates a whistle with a single high-pitched note placed well forward on the locomotive. This change would result, he says, in a saving of many lives and of two-thirds of the coal now used—a money saving of over four million dollars.

Sounds produced by moving currents of air, or by high winds, are among the most common of our every-day experience. They are so common that we seldom stop to inquire closely into the nature of the mechanism producing the sounds. Many an old deserted house has owed its reputation for "haunts" to accidental peculiarities of structure which call forth uncanny moanings and groanings whenever a high wind is blowing. The Rice Institute Library at one time possessed one of these "haunts"; its supernatural character, however, was entirely eliminated by the presence of substantial brick walls, and also perhaps by stacks of books dealing with the theory of vortex motions in a turbulent medium. Forests have individual sounds depending upon the kind of trees which predominate. Pine woods produce a soft, high-pitched noise. Forests of oaks give off a dull roar. The causes of these differences of sound are not hard to find.

Consider a current of air flowing past an obstacle, say a stretched wire. We might expect that the air current which is divided by the wire would come together smoothly again after passing it, leaving perhaps a more or less turbulent region immediately behind the wire. Such, however, is not the case. The wind, passing by the wire, forms little eddies or whirlpools, first on one side of the wire, then on the other. It is easy to see that when these little whirls form they may give rise to lateral variations of pressure on the surrounding air. If these lateral pressure variations occur rapidly enough, a sound is produced. It is usually very feeble. Suppose, however, that the wire is not rigid. Then these little whirls forming alternately, first on one side of the wire, then on the other, may set it in motion, may make it vibrate. Of course the side pushes are very feeble, but if they come at just the right time they can produce quite a large motion of the wire. If I tap a suspended pendulum very gently I can still make it swing very vigorously, provided I time the impulses correctly. It appears, therefore, that if the side pushes on a telegraph wire come at just the right times to make it vibrate the way it naturally tends to vibrate, then a big motion can result. The wire in this case gives off a loud, humming noise, as if it were bowed by a violin bow. This hum is known as an Æolian tone. Now, it happens that the rate at which the little air whirls are formed depends on the velocity of the wind. Consequently it is only when the wind has one particular velocity that we hear the telephone or telegraph wires hum. For this wind velocity the frequency with which the little air whirls form is exactly the same as the frequency with which the wire tends naturally to vibrate.

When the wind blows past a broad flat surface, like the leaf on a tree, conditions are somewhat different, but there is still the same tendency for vibrations of the leaf to be set up. The nature of the sounds produced by such vibrations is of course affected by the form and size of the leaf. As I mentioned previously, the blind naturalist, Mr. Wilkinson, could name the variety of a tree by listening to the breezes blowing through its branches. He could distinguish between spring, summer, and fall by the changes in the character of these tree sounds as the season advanced and the leaves grew larger. The sound of the wind in a forest is a combination of Æolian tones from twigs and branches, with sounds made by vibrating and rustling leaves and branches. The net result may amount to a dull roar, the character of which changes with the velocity of the wind. It is said that in certain regions natives use forest sounds in forecasting the weather, a certain forest tone having been found to be the almost invariable precursor of a storm.

A question which was investigated a number of years ago by Lord Rayleigh is the following: how are we able to tell so accurately the direction from which a sound is coming? It appears that there are two factors to consider in this connection. If a sound comes towards me from the right it is a little bit weaker at my left ear than at my right. This factor is found to be not very important as far as locating the sound is concerned. The second factor is more important. If the sound comes towards me from the right it hits my right ear before it hits my left. The brain is able to detect this time factor and interpret it as a direction effect. The phase difference, as it is called, of the sound at the two ears is in most cases the decisive factor in locating sound sources. Since two ears are required, this ability, or this direction sense, is called the binaural sense.

If the sound strikes both ears simultaneously, it may appear to come from directly ahead, directly behind, or directly overhead, unless by turning the head one ear is moved farther from the source than the other. An intelligent dog, when listening to a faint sound, will cock his head first one way then the other. He has learned that in this way he can bring his binaural sense into play and locate the sound more accurately.

It is found that the binaural sense is considerably sharpened by the use of long listening horns attached to the ears. These horns have the effect of extending the ears, or of making the distance between the two ears much greater; the sound difference at the two ears is thus magnified. By using these horns it is possible to locate quite accurately the position of an airplane which may happen to be doing some night flying. We have to remember, however, in shooting at the airplane, that it may take several seconds for the sound to reach us from the distant machine, and during that time the plane will have moved on quite some distance. It will always be ahead of the place from which its sound appears to come.

The locating of big guns is a much simpler matter than the locating of airplanes, first, because a gun is confined to the surface of the earth and we only have to worry about two dimensions; second, because the noise of a gun consists of a single big sound wave, while that from an airplane is a series of waves. Also the gun is not apt to be a moving target. The method used by the British Army in locating big guns was simple and effective. At six different stations, well separated from each other, were placed microphones (very sensitive telephone transmitters). Wires from these microphones led to a central station where each microphone was connected with its own recorder. The sound wave from a big gun would strike the different stations at different times, since some would be nearer the source than others. These different times were all recorded on a moving strip of moving picture film. It was a matter of only a few minutes to develop the film, calculate the position of the enemy gun from its sound record, and telephone the proper range to the British batteries. The average error in calculating the position of a gun six miles away was only fifty yards. It is said that this method of locating big guns was responsible for putting more of them out of commission than any other method.

The locating of submarines by sound is a problem which was made familiar to many people. The exigencies of submarine warfare brought the methods in use to the front pages of the daily papers. There are different kinds of sound detectors for use in water. Here I will take time to mention only one—the simplest one. If we think of the water in the ocean as a medium which can transmit sound just as air transmits it, but four and a half times faster, we immediately think of locating sounds in water just as we locate them in air, by the use of the binaural sense. Obviously we cannot stick our heads under the water to hear these sounds, and since they do not come out into the air we must devise some way of getting at them. It is found that a stethoscope, very similar to the ones used by physicians, when immersed in water will pick up sounds. With a stethoscope connected with each ear the binaural sense comes into play and it is not very difficult to determine quite accurately the direction of the sound. It is largely due to the very extensive study, made during the war, of sound in water that we have two important practical developments. Instead of the old-time methods of sounding for depth with a line and sinker, the modern method uses a sound wave.

A ship sends out a sound into the water and listens for the echo from the ocean bottom. The time elapsing before the echo is heard gives the depth of the ocean, since the velocity of sound in salt water is known very accurately.

The second development is in connection with fog signalling. Recently the Submarine Signal Company has installed at the Fire Island Light near New York Harbor a signalling station which operates as follows. A series of sharp signals (dots) are automatically sent out both by radio and by submarine sound. They are sent out over both routes, the water route and the ether route, simultaneously. Now the radio signal travels about forty miles while the sound signal is travelling a distance of one foot. Hence when an observer on a ship receives the radio signal he knows the sound signal is just starting out. Suppose he gets the sound signal, say ten seconds later. Then he knows he is nine miles from the station, because sound will only travel nine miles in ten seconds through salt water. The radio receiver will give the direction of the station from the ship, so that its location is completely determined. This interesting method of safeguarding ships in fog or darkness will very probably be extended and developed, so that in the near future a sound receiver will be a regular equipment of all ships just as the radio now is.

There is one more phase of this subject, the locating of sound sources, about which not so much has been written. We have seen that the binaural sense is used for locating sounds in the air and in the water; it is also used for sounds in the solid earth. We have all read about the Indian scout who places his ear to the ground in order to hear the approach of his enemy. The modern warrior has improved on the ear. He uses a geophone, an instrument constructed as follows: A wooden box contains two partitions of thin mica, the space between being filled with mercury. Tubes lead from the air chambers on each side of the mercury. These tubes are connected with the ears. If this device is laid on the ground, the box picks up the sound vibrations, but the mercury, being very heavy, does not vibrate with the box. It is clear, then, that the air in the box will be compressed and rarefied as the box vibrates, so that the sound can be heard through the tubes.

In locating the source of a sound, one tube from the geophone is corked up, the other connected with one ear. A similarly arranged geophone is connected with the other ear. These two geophones are then laid on the ground at some distance from each other and shifted about till the sound appears to come from directly ahead. The source is then either directly ahead or directly behind the observer. Very little has been published about the use of geophones during the war. One account tells of a British mining party hearing sounds from a German countermine. These sounds steadily became louder till the voices and laughter of the Germans could be heard. However, repeated tests with the geophones indicated that the Germans would miss the British mine, so work was rapidly continued, the tunnel completed, and an enemy defense blown up. The geophone, you see, warned the party of danger; it also assured them of safety if they worked rapidly and quietly.

The war, as I have said before, brought to light new problems in the field of sound, and many of these problems were solved. There is one interesting phenomenon, however, which has as yet not been explained in a completely satisfactory way. It has been found that as one goes farther and farther away from a locality where heavy bombardment is going on, the sound grows fainter and fainter till it becomes inaudible. The surprising thing, however, is that by going still farther away one can hear the sound again. In other words, there appears to be around a source of loud explosive sounds, a zone of silence, perhaps fifty miles wide, and perhaps fifty miles distant from the source. Outside this zone the sound is heard. The following explanation has been suggested: When the sound travels outwards and upwards it enters upper regions of the atmosphere, where the percentage of lighter gases like hydrogen and helium is greater. A sort of reflection would result. (We have seen that sound is reflected when it encounters a change in the medium.) This reflection would cause the sound to return to earth again where it could be heard, at distances of one or two hundred miles from the source, outside the so-called silent zone. There are objections to this theory, but it is about the best explanation yet given.

Associated with these loud noises of guns or explosions are inaudible sound waves. Windows rattle sometimes before the sound is heard, sometimes afterwards. A lady thirteen and a half miles from an East London explosion was powdering her nose in a calm atmosphere. Suddenly a puff of powder rose from the open powder-box. Shortly after this she heard the sound of the explosion. A hundred and fifteen miles from the explosion windows rattled before the noise was heard. In the zone of silence there was no noise, of course, but windows rattled and pheasants were much disturbed, screeching in an extraordinary way at eight different localities where observations were reported.

It appears, therefore, that there are long sound waves, or air pulses, produced by explosions, which travel farther than the audible sounds, and it is these air pulses which break windows, affect barometers, and frighten pheasants. At the time of the Krakatoa eruption such a wave is believed to have gone completely around the earth three times.

It remains for future investigations to settle the exact nature of these waves, and also the exact cause of the silent zones, through which the long inaudible wave appears to travel while the audible is excluded.

Silent zones and long inaudible sound waves are not observed frequently enough for us to become thoroughly familiar with them. An element of mystery is therefore to be expected. There is, on the other hand, a whole group of very familiar phenomena which are more or less shrouded in mystery as far as general popular knowledge is concerned. Every one knows that in some halls or auditoriums it is very difficult to understand a lecturer. In others musical performances are not successful. The reason for these bad acoustic properties of certain buildings is not a matter of common knowledge. There are many well-known architects who appear to leave the acoustics of their buildings almost entirely in the hands of the god of chance, with the result that some strange anomalies have been produced. Cathedrals with interiors which delight the eye have been made the playground of little demon echoes which bound from vaulted roofs and fluted pillars to confound the ear of devout auditors. In the attempt to snare these demons miles of wire have been strung about the interiors of churches and auditoriums—all to no purpose whatever. They cannot be caught on wires. They are most successfully stopped by sheets of soft hair-felt, such as is used as a ceiling in our City Auditorium, but unfortunately hair-felt can sometimes look too much like a haven for rats to appeal to the interior decorator as a suitable medium for self-expression. The problem, of course, is one which should be settled before it arises. The architect of a building to be used for public speaking or for musical performances should be familiar with the principles of architectural acoustics, or he should secure the services of an expert in this line.

Each building usually presents its own problems, but there are certain general rules which have been worked out and which are easy to apply. Suppose I clap my hands in this auditorium. The sound can be heard for an appreciable time. With no audience in the room the sound lasts a little over three seconds. It is easy to see why the sound persists, why we have this reverberation, as it is called. The sound from my hands strikes the walls, is reflected, passes through the room, is reflected from the opposite walls, and so on, growing weaker at each reflection because some of the sound is absorbed by the walls at each reflection. In this room, when it is empty, the noise of a handclap travels well over half a mile before it becomes too weak to affect the ear.

Now consider the effect of this reverberation in the case of a rapid talker. While the sound of one syllable is still ringing in the ears of the audience he may utter four or five more. The result is a confusion. Sounds of different syllables or of different words are superposed upon each other. The louder the speaker talks the worse is the confusion of sounds. Yet he cannot talk too feebly or he will not be heard. His only recourse is to talk slowly and distinctly. In some halls the reverberation time is six or seven seconds. Obviously a lecturer who confined himself to even three syllables in six seconds would be intolerable. Hence some halls cannot be used for lecture purposes. Cathedrals usually have a long reverberation time. Recently an eminent English authority on sound warned newly-appointed rectors that their sermons must consist of just half the usual number of words; otherwise their sermons would not be understood.

As a result of the researches of W. C. Sabine we have a very simple way of cutting down the reverberation time. It is found that soft, porous materials, like cushions, draperies, etc., absorb sound. Sabine has shown that a certain area of sound-absorbing material is effective in cutting down reverberation no matter where it is placed in the room. This result is to be expected, for if a sound wave travels half a mile in this room, it is pretty sure to have been reflected at least once from every wall and pillar in the room. No matter where a curtain of absorbing material is placed, therefore, it will be hit by the wave and will absorb some of the sound.

The absorbing power of different materials has been investigated. For example, it is found that an oriental rug is about 0.3 as good as an open window of the same size in absorbing sound. Hair-felt is .78 as good. An isolated man is .48 as good as an open window; an isolated woman is .54 as good. With exact data such as this it is easy to see that the reverberation time of an auditorium can be calculated from a knowledge of its dimensions and the materials which it contains. Experience has shown that for speaking purposes the reverberation time for a hall of volume 216,000 cubic feet, when empty, should not be, in general, greater than three seconds. Consequently, since we know what the reverberation time should be, and since we know how to reduce this time at will, the problem can be solved quite easily. If a given hall is suffering from excess reverberation, the specialist should be able to diagnose the case without leaving his office, and should effect a cure by prescribing so many yards of chenille curtains, so many oil paintings, so many rugs or carpets, etc. He cannot prescribe a certain size of audience, so he does the next best thing—prescribes cushions for the seats. An unoccupied cushion is about half as good as a man at absorbing sound.

One reason why the best theatres have soft cushioned seats is that the acoustic properties of the theatre are then more nearly independent of the size of the audience.

The reverberation time depends to some extent on the pitch of the note. Two ministers were candidates for the pulpit of a certain Boston church. The first candidate, with a loud, low-pitched voice, failed to secure the appointment because the audience could not understand him. The successful candidate had a less powerful voice, but it was higher in pitch and was easily understood. Many of us have noticed this peculiar aptitude of certain rooms to respond, or resonate, to notes of certain pitch. It has been pointed out that the average man is most apt to burst into song while taking his morning bath. The probability is that the reverberation of the bathroom, which is freer from heavy draperies than any other room, seduces the singer into the belief that he possesses a peculiarly powerful and resonant voice—a belief which is often shattered by subsequent trials in a less favorable environment.

Reverberation is not the only source of trouble in the acoustics of auditoriums. There may be peculiar echoes. On one occasion the University of Illinois band was playing in their University auditorium. A xylophone solo with accompaniments by other instruments was featured. It so happened that the leader heard an echo more strongly than the direct sound of the xylophone, so he beat time with the echo. Players near the xylophone kept time with the direct sound. It is said that the confusion resulting was worse than is usual even in college bands.

The elimination of echoes such as this is secured by the elimination of large, flat surfaces which can reflect a great volume of sound in one direction. Practically all modern theatres have their walls and ceilings broken by recesses, coffering, and bas-relief. In addition to being decorative, these devices are often essential for the prevention of disturbing echoes.

In the history of architecture we find several instances where chance designs have resulted in extraordinary effects due to echoes. Faint sounds made in one part of a hall can sometimes be heard with startling distinctness at a far distant part of the room. A hall exhibiting this phenomenon is called a whispering gallery. Consider a room with a large smooth dome. A sound wave started at the centre strikes all parts of the dome simultaneously and is reflected back perpendicularly. The reflected wave converges to a point, in this case, the source, but it is easy to see that changes in the shape of the dome could cause the convergence point to be at some distance from the source. At this convergence point the original sound is very distinctly heard.

There are six whispering galleries in the world which have been made famous by some incident of place or association. They are the dome of St. Paul's Cathedral in London, Statuary Hall in the Capitol at Washington, the vases in the Salle des Cariatides in the Louvre in Paris, St. John Lateran in Rome, the Ear of Dionysius at Syracuse, and the Cathedral of Girgenti, Sicily.

The simplest of these and possibly the most perfect was the one at Washington. The guide would place tourists at symmetrical points beneath the large dome and they could carry on a whispered conversation across a very large distance. In the course of time deep hollows were worn in the marble tile where the observers stood. At present this unique property of the hall has largely disappeared because of repairs made on the dome. The smooth reflecting surface has been broken by coffering. Regarding the

Cathedral of Girgenti in Sicily, Sir John Herschel in the Encyclopedia Metropolitana says: "In this cathedral the slighest whisper is borne with perfect distinctness from the great western floor to the cornice behind the high altar, a distance of two hundred and fifty feet. By a most unlucky coincidence the precise focus of divergence at the former station was chosen for the place of the confessional. Secrets never intended for the public ear thus became known, to the dismay of the confessor and the scandal of the people, by the resort of the curious to the opposite point, which seems to have been discovered by accident." Sabine is inclined to doubt this story of Herschel about the eavesdroppers because of the very conspicuous position which they would be forced to occupy.

In the Salle des Cariatides in the Louvre are two shallow antique vases quite far apart. By a curious freak of construction a whisper uttered a little within the rim of one vase is partially focussed by it, still further focussed by the barrel-shaped ceiling, and is finally heard very distinctly just within the rim of the second vase. The Ear of Dionysius is the remains of an old quarry about a mile out from the present city of Syracuse. Tradition has it that Dionysius, the builder of Syracuse, once used this grotto as a prison. Being apparently a man of considerable ingenuity, he so designed his prisons that there was one point from which he could not only see everything going on in the prison, but could also hear everything that was said. The old quarry is supposed to have been one of these prisons. At present it possesses interesting acoustical properties, but the favored point from which one can see all and hear all is not as satisfactory as could be desired. True, it is on an upper level, fairly well sheltered, but reverberation renders difficult the understanding of words uttered on the main floor.

These examples which I have cited are all accidents—with the possible exception of the ear of Dionysius. It seems probable that with the knowledge we now have of sound and its behavior the functioning of most of these accidental whispering galleries could be improved by suitable changes of design. An architect or builder with the wealth and inclination of a Dionysius could easily surpass the works of the old tyrant of Syracuse. A business man, for example, who objected to the proximity of his stenographer could place her desk at a far corner of the room at a sound focus. By locating his own desk at the conjugate focus he could dictate to her, or carry on whispered conversations, no one else in the room being disturbed by the talk, or indeed, even being aware of it.

As far as I know, there is only one whispering gallery in the world which is not an accident—which was designed with the intention of being a whispering gallery. This is the dome of the State Capitol of Missouri. The completed structure is said to have fulfilled all expectations and is a source of great interest and astonishment to tourists.

In a discussion of sound and its applications very many people would rank as of fundamental importance a branch of the subject which I have not as yet even mentioned, namely, musical sounds. Any sound is said to be musical if the sound waves striking the ear are all similar and evenly spaced; hence musical sounds obey the same general laws as noises. There are also special laws governing the combination of different musical sounds to produce harmony or dissonance. Musical sounds are unique among other kinds of sound in that they possess the power of influencing and affecting thousands of people, perhaps more than any other kind of stimulus received through the sense organs. People can be influenced by music who are impervious to reason. To other people musical sounds mean no more than a succession of noises. In a physical sense these two classes of people are similar; they both have the same mechanism for hearing the sounds, the vibrating tympanum, the cochlea with its rods of Corti, etc., but there the resemblance ceases. The interpretative power, or value sense, is entirely different in the two groups of people.

It may be well, in a lecture which has emphasized so much the mechanism of sound, to mention, at least, the possibilities of enjoyment which may result from the development of this value sense for music. People who possess it certainly have open to them fields of pleasure which are closed to less favored mortals. It is possible to acquire a taste for music, though hardly through listening to a discussion of wavelengths, frequencies, overtones, or Fourier's series. I have found a highly imaginative description of the sensations and pleasures which, possibly, many people experience when their ears are subjected to the ordered impacts of carefully chosen sound waves. This selection is from the letters of Sidney Lanier, the poet-musician. He says: " 'Twas opening night of Thomas' orchestra, and I could not resist the temptation to go and bathe in the sweet amber seas of this fine music, and so I went, and tugged me through a vast crowd, and after standing some while found a seat, and the baton tapped and waved, and I plunged into the sea, and lay and floated. Ah, the dear flutes and oboes and horns drifted me hither and thither, and the great violins and small violins swayed me upon waves, and overflowed me with strong lavations, and sprinkled glistening foam in my face, and in among the clarinetti, as among waving water lilies with flexible stems, I pushed my easy way, and so, even lying in the music waters, I floated and flowed, my soul utterly bent and prostrate." No one but a poet would dare express his feelings in this way in an ordinary letter. The quotation indicates, however, an ecstasy of pleasure such as nothing else can inspire. Could all of us possess even a small part of such enthusiasm as Sidney Lanier's, we should undoubtedly feel deeply grateful.

Having read a poet's description of musical sounds, I want to close this lecture with another quotation, which, it seems to me, might have been written by a music lover with a sense of the scientific. It is from "Peter Ibbetson" by Du Maurier. "The hardened soul melts at the tones of the singer, at the unspeakable pathos of the sounds which cannot lie; . . . One whose heart, so hopelessly impervious to the written word, so helplessly calloused to the spoken message, can be reached only by the organized vibrations of a trained larynx, a metal pipe, a reed, a fiddle string—by invisible, impalpable, incomprehensible little air-waves in mathematical combinations, that beat against a tiny drum at the back of one's ear. And these mathematical combinations and the laws that govern them have existed forever, before Moses, before Pan, long before either a larynx or a tympanum had been evolved. They are absolute!"

CLAUDE W. HEAPS